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Prediction and Optimization of Surface Roughness in Hard Milling of SKD61 Steel by using Taguchi Method

The-Vinh Do

Thai Nguyen University of Technology, Thai Nguyen City, Vietnam

ABSTRACT

SKD61 steel is a type of steel widely used in the industry. In this study, the Taguchi method was used to optimize the cutting parameters to achieve the smallest surface roughness when milling SKD61 alloy steel. The three parameters of the cutting process, namely cutting speed, feed rate and depth of cut, were selected as input factors and evaluated at three levels: low, medium and high. Analysis of variance (ANOVA) was used to analyze the influence of each input factor on the surface roughness. The results showed that the feed rate was the most influential factor on the surface roughness, followed by cutting speed and depth of cut.

KEYWORDS: *hard turning; SKD61 alloy steel; Taguchi method; surface roughness*

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INTRODUCTION

SKD61 steel has many good mechanical properties such as corrosion resistance, high strength at high temperatures, and good hot cracking resistance[1]. Therefore, SKD61 is very suitable for use in the mold industry, especially in hot forging. The research on improving the efficiency of the SKD61 steel cutting process has been pursued by many researchers

Surface roughness in machining is an important parameter for evaluating the quality of machining. Minimizing the surface roughness in machining processes is an attractive topic for researchers in various cutting processes such as turning[2], [3], milling[4]–[6], grinding[7], [8] etc. Using optimization tools to find the optimal machining conditions to achieve minimum surface roughness is a common approach in research. Among them, the Taguchi method is a powerful and easy-to-use method[9]. The Taguchi method analyzes the Signal-to-Noise (S/N) ratio to find the optimal level of input factors. In addition, this method also identifies the factor that has the greatest impact on the output response

In cutting processes, three important cutting parameters are provided to evaluate: cutting speed, feed rate, and cutting depth. Optimizing these parameters has been carried out in many studies including studies on turning[10], [11], milling[12]–[15], grinding[16], [17], etc. In general, previous studies have a common observation that machining with small feed rates, small depth of cut, and high cutting speeds will achieve a fine surface finish[18], [19].

In this study, the process of milling hardened SKD61 steel was conducted under Minimum Quantity Lubrication (MQL) machining conditions. The Taguchi method was applied to investigate the influence of input factors, including cutting speed, feed rate, and tool approach, on the output response of surface roughness. A predictive function for surface roughness was also established.

EXPERIMENTAL PROCEDURE

All experiments were conducted on a 5-axis milling machine DMU50. The SKD61 steel

workpiece was heat-treated to achieve a hardness of 50HRC. The cutting tool used was a D10 solid carbide end mill. The steel workpiece was securely clamped on the universal fixture. The MQL nozzle was attached to the machine's tool head. The cutting fluid flow rate was set at 50ml/min, and the compressed air pressure was 3 kg/cm2. Surface roughness was measured using a Mitutoyo SJ-401 roughness tester. The cutting parameters at three levels are presented in Table 1.

TABLE 1: PARAMETERS AND LEVELS

Parameters	Levels		
	1	2	3
Cutting speed (m/min)	40	70	100
Depth of cut (mm)	0.15	0.3	0.45
Feed rate (mm/min)	0.01	0.02	0.03

TABLE 2: TABLE OF EXPERIMENT RESULTS

v (m/min)	d (mm)	f (mm/rev)	Ra (µm)	S/N
40	0.15	0.01	0.363	8.8019
40	0.30	0.02	0.642	3.8493
40	0.45	0.03	0.891	1.0024
70	0.15	0.02	0.489	6.2138
70	0.30	0.03	0.880	1.1103
70	0.45	0.01	0.390	8.1787
100	0.15	0.03	0.694	3.1728
100	0.30	0.01	0.249	12.0760
100	0.45	0.02	0.584	4.6717

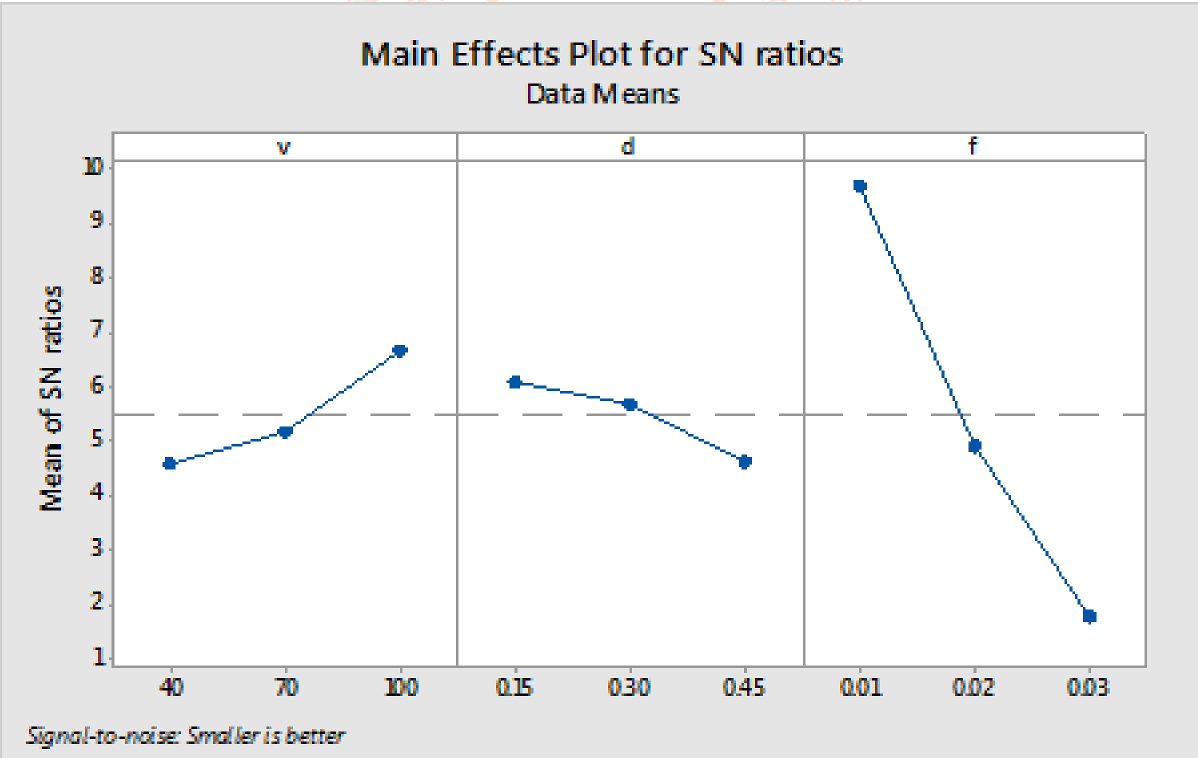

FIGURE 2: S/N RATIO PLOT

RESULTS AND DISCUSSIONSRESULTS AND DISCUSSIONS

The results of the experiments are presented in Table 2. The roughness values range from 0.249µm (Experiment 8) to 0.89 µm (Experiment 3). The statistical analysis was performed using Minitab V17 software. The Signal-to-Noise (S/N) ratio values are also shown in Table 2.

The response values for each level of the input factors are presented in Table 3. The difference between the minimum and maximum values of the levels of the input factors reflects their impact on the output response (roughness). It can be observed that the difference between the levels of the feedrate is the largest (Delta equals 7.924). This indicates that the feedrate is the most influential factor on the roughness, followed by cutting speed and depth of cut.

TABLE 3: RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Level	v	d	f
1	4.551	6.063	9.686
2	5.168	5.679	4.912
3	6.640	4.618	1.762
Delta	2.089	1.445	7.924
Rank	2	3	1

The Response S/N analysis is shown in Figure 1. It can observe that the optimal conditions for achieving the lowest roughness are the highest cutting speed, the lowest depth of cut, and the lowest feed rate. The difference between the maximum and minimum points of the feed rate has the largest value, indicating that the feed rate has the greatest influence on the roughness.

The analysis of variance is presented in Table 4. According to the analysis of variance, feedrate is the factor that has the greatest influence on the machining roughness, followed by cutting speed and depth of cut. Feedrate accounts for 88.2% of the total influence. The p-values of all the parameters are less than 0.05, indicating that the influences of the selected parameters are statistically significant. Additionally, Table 4 also provides the values of the coefficient of determination, R-squared. The value of R2 = 98.01 indicates that 98.01% of the variation in roughness can be explained by the selected input factors in this study.

TABLE 4: ANALYSIS OF VARIANCE TABLE

Source	DF	Adj-SS	Adj-MS	F-Value	P-Value	C%
Regression	3	0.396382	0.132127	81.91	0.000	98.0
v	1	0.022693	0.022693	14.07	0.013	5.61
d	1	0.016960	0.016960	10.51	0.023	4.19
f	1	0.356728	0.356728	221.14	0.000	88.2
Error	5	0.008066	0.001613	-	-	
Total	8	0.404448	-	-	-	
R-sq = 98.01%						

A mathematical regression model for predicting surface roughness was constructed using the Minitab software (1).

$$Ra = 0.1253 - 0.002050\,v + 0.354\,d + 24.38\,f \quad (1)$$

CONCLUSION

This study aimed to optimize the cutting parameters to minimize surface roughness in the hard milling process of SKD 61 alloy steel under Minimum Quantity Lubrication (MQL) cooling conditions. The investigation focused on three crucial cutting regime parameters: cutting speed, feedrate, and depth of cut. The results were analyzed using the Taguchi method and ANOVA. The following conclusions can be drawn:

Feedrate exerts the most significant influence on surface roughness, followed by cutting speed and depth of cut.

The optimal machining process for achieving the smallest surface roughness involves utilizing the highest cutting speed, the lowest feedrate, and the shallowest depth of cut.

A reliable mathematical regression model was developed to accurately predict surface roughness.

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